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Simulation of Energy Consumption for Different Types of Walls and Colour for A Residential Building, Case Study: Phnom Penh City, Cambodia

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ABSTRACT

The residential building sector in Cambodia is growing rapidly, with the number of flats increasing by more than 34% from 2020 to 2021. This growth is putting a strain on the country's energy resources, as air conditioning (HVAC) systems account for a significant portion of energy consumption in buildings. This study used EnergyPlus™ with OpenStudio SketchUp Plug-In to simulate the annual energy consumption of a flat in Phnom Penh, Cambodia. The calculated annual energy consumption agrees well with actual electricity consumption accumulated from monthly electricity bills, with error of 1.78%. The results showed that the selection of colour paint and additional insulation on the existing wall can reduce annual energy consumption by 3.20% and 19.68%, respectively. These findings suggest that energy efficiency measures can play a significant role in reducing energy consumption in the residential building sector of Cambodia. However, it is important to note that the results may vary depending on the specific building design, occupancy behaviours and climate conditions.

1. INTRODUCTION

As a developing country, Cambodia faces significant concerns regarding its predicted population increase. Currently, Cambodia has a population of approximately 15,552,211, and this number is expected to grow annually by around 1.4% [1]. Moreover, the rapid growth of Cambodia's population has led to a considerable increase in residential buildings. In fact, the number of flats in Cambodia has surged by 34%, rising from 21,074 in 2020 to 31,984 in 2021 [2]. However, this surge in residential building construction has resulted in a corresponding surge in energy demand and consumption, which poses a major environmental challenge. Specifically, residential buildings in Cambodia are significantly contributing to the country's overall energy consumption. In 2018, the residential building sector accounted for approximately 19.4% of Cambodia's total energy consumption, primarily in the electricity sector. Alarmingly, this figure has witnessed a significant rise of around 24% since 2017 [3].

The type of wall construction used in buildings can play a significant role in energy conservation. The bricks and insulation layers can help to reduce heat transfer through walls, which can lead to lower energy consumption. The walls have a significant impact on reducing AC energy costs, which can contribute to lower overall building energy consumption. The right wall material can greatly reduce AC energy use [4]. Similar to previous studies, research on wall design that improves performance and reduces heat transfer can be divided into three groups: developing new types or models of walls; building walls with various properties and characteristics; and modelling and optimizing the combination of walls with additional insulation [5].

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A study conducted to evaluate the effectiveness of various wall materials in terms of their energy-saving capabilities [6]. The researchers utilized Building Information Modelling (BIM) software to model the walls and then simulated their performance using specialized software. The findings of the study indicated that by modifying the wall materials and identifying the most optimized options, significant energy savings could be achieved. Through energy analysis and the implementation of the best-performing wall materials, the study demonstrated an impressive electrical energy savings of 9347 watt-hours per square meter. This outcome highlights the potential for substantial energy conservation by making informed choices regarding wall materials. Within the investigation, the theoretical calculations and test detection of the thermal performances of concrete block, cavity wall made of brick, non-clay brick wall, rectangular block construction, composite ceramic concrete block construction, steam-pressed sand concrete block masonry with gas, and concrete porous brick wall [7]. They conducted this research based on the current state of building wall materials in rural buildings, which consume significant amounts of energy and have poor thermal performances. Utilising the weighted average approach, the test results and theoretical calculation results of the wall heat transfer coefficients are processed. The result showed that influencing parameters such as mortar thickness, wall thickness, and the thermal conductivity of the wall materials all demonstrated decreasingly negative correlations with the wall heat transfer coefficient.

The optimization of combinations of materials to construct walls of buildings can improve building performance. By developing a wall type with appropriate component layers, the ideal insulation thickness can be determined. They analysed the best insulation thickness for the environment and building construction using a variety of wall types, including brick, concrete, and stone [8]. Extruded polystyrene (XPS) and Expanded polystyrene (EPS) were nominated as insulation materials. The results showed that the ideal insulation thickness ranges between 5.2 and 7.4 centimetres and energy savings between 2560 and 5510 Rs (equivalent to around 31 and 66 USD for exchange rate at the time of this writing) per square meter per year, depending on the cost of fuel, the climate, the cost of the insulation material, and its thermal conductivity. The study conducted by [9] investigated the effectiveness of a selectable insulation system used in an external envelope system. They conducted a complete rotation of on and off insulation on the exterior, interior, or both sides of a mass wall system. An evaluation process on a 101.6 x 203.2-mm surface was carried out in a climate chamber to verify the simulation work. The results showed that the selectable insulation on the external side of the wall system produced the maximum interior inward heat flux, compared to the interior or split insulation.

Energy simulation is a computer-based analytical procedure that enables building owners and designers to assess a structure's energy efficiency and make required design changes before it is built [10]. Energy simulation tools are essential for making informed decisions about the impact of different energy efficiency strategies on energy consumption within a building [11].

Various types of building energy simulation software are available, such as EnergyPro, EnergyPlus, EAB, REScheck, etc. [12]. Among these, EnergyPlus, created by the US Department of Energy, is becoming popular for simulating and designing energy-efficient buildings. EnergyPlus is a building energy analysis programme with thousands of users worldwide, capable of measuring the energy consumption of buildings based on their envelope design, HVAC system design and controls, and climate and occupancy data [13].

EnergyPlus is a free, open-source, cross-platform simulation engine that does not have a graphical user interface (GUI) but can be used in conjunction with third-party GUIs if the user deems them essential [14]. The 3D graphical interfaces SketchUp and OpenStudio Plug-In are often used along with the whole-building simulation software EnergyPlus to model and simulate the energy performance of a facility [15]. The main goal of this research is to compare types of walls that addition of insulation to existing single-brick walls & double-brick walls, and investigation the selection of paint colour by using EnergyPlus software from the energy point of view. The study aims to reduce energy consumption in residential buildings due to the wall and to analyse the influence of related parameters.

This study investigated how various wall layers with insulation options and colour paint typically used in Cambodia affect yearly energy consumption. The purpose of this study was to propose three options for simulation in the flat to address the flat retrofitting for energy saving. The investigation included an annual energy consumption evaluation, which compared simulation results from different scenarios with actual annual energy consumption to determine how much energy can be saved.

The three proposed options are:

- Investigation on the possibility of the existing wall with an additional insulation layer.
- Comparison of the characteristics of a double-brick wall and an existing single brick wall.
- Examination of the potential of choosing paint colours that have an impact on energy savings in the residential building, which has an impact on energy efficiency.

2. METHODOLOGY

2.1 Specification and characteristic of flat in the modelling

In this case study on energy efficiency in a building in Phnom Penh, Cambodia, a flat that was completed in 2019 but only occupied in 2020 was selected as a model for simulation of energy consumption.

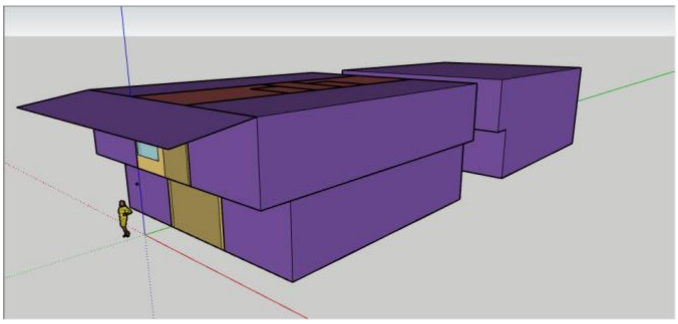


Fig. 1. SketchUp model of the flat under investigation

The flat is a two-story townhouse style with E0 and E1 floors. The E_0 floor is divided into three spaces: the living room at the front, the kitchen and storage at the back, and a bathroom in between. The E_1 floor is divided into two bedrooms: the children's bedroom at the front and the parents' bedroom at the back. Each bedroom is equipped with split air-conditioning.

The building selection focused on flat buildings, which have become the most prevalent housing model in Cambodia, as reported by the "Cambodia Inter-Censal Population Survey 2021." These buildings use various materials, including different roof types, walls, and floors. Like many townhouses in the country, these flats are constructed with single-brick walls without insulation and rely on natural ventilation in this case study.

2.2 Building Envelope of the initial case

The flat model used for simulation is a mezzanine flat with the building envelope made of hollow brick with cement mortar, and the exterior of the wall is covered by cement plaster with a thickness of 15 mm. The roof is a flat roof covered by five layers that include ceiling, air space, reinforced concrete, mortar, and clay floor tiles. The orientation of the facade residential building is north. For the fixed glazed windows and exterior doors used with aluminium frames. The shading of the other flats on the outside is included also. The window is a sliding thermally controlled single glass with transparency that has shown in table 3, and other thermal properties of the material are listed in the table 1. The other required properties for the modelling are given in Tables 2 and 4.

Table 1. Thermal Properties of Construction Materials

Material	Thickness (mm)	Thermal Con.(W/m.k)	Density (kg/m^3)
Hollow Brick[1]	100	0.52	1300
Cement Plaster[1]	15	0.87	1700
Ceiling Board[1]	9.5	0.35	840
Ceramic Tile[2]	8.5	1.05	2200
Reinforced[2]	70	1.55	2400
Wood Door[2]	40	0.35	550
Exterior Glazed[1]	5	0.78	2500
Cement Mortar[1]	60	1.15	1800
Color Paint	0	0	1050
Clay Floor Tile[2]	10	0.85	1900
ESP Insulation[2]	50	0.05	24

[1] National Technical Regulation Energy Efficiency Building, Vietnam: QCVN 09:2013/BXD.
[2] The Harmonization of Thermal Properties of Building Materials, Technical Note 91/6.

Table 2. Thermal resistance of unventilated air layer*, m^2K/W

Air layer thickness (mm)	Heat flow direction		
	Horizontal (vertical air layer)	*Upward (horizontal air layer)*	*Downward (horizontal air layer)*
0	0.00	0.00	0.00
5	0.11	0.11	0.11
7	0.13	0.13	0.13
10	0.15	0.15	0.15
15	0.17	0.16	0.17
25	0.18	0.16	0.19
50	0.18	0.16	0.21
100	0.18	0.16	0.22
300	0.18	0.16	0.23

* Accordance with TCVN 298:2003 and ISO 6946:1996 standard.

Table 3. The properties of the clear single-glazed window*

Specification	Value
U-factor	5.84
Solar Heat Gain Coefficient (SHGC)	0.77
Visible Transmittance	1.02

* Accordance to NSG Group (Architectural Glass Product guide Pilkington North America).

Table 4. Absorptivity for common colors[a,b]

Color	Solar Absorptance
White	0.35
Green	0.47
Ochre	0.6
Dark Beige	0.7
Blue	0.7
Red	0.75
Brown	0.75
Dark Brown	0.83
Dark Colors	0.9
Black	0.95

[a] Insulation Materials For Undergraduate Students4th Class by Al-Mustansiriyah University, Republic of Iraq.
[b] Solar Absorptance face sheet from ARTA Australian roofing Tile Association.

2.3 Energy Modelling Simulation

The OpenStudio (version 1.2.0) energy modelling program, which uses the tested EnergyPlus (version 9.5) hourly simulation engine, was used to evaluate the as-built residence and the various insulation possibilities. EnergyPlus is a building energy modelling software developed by the US Department of Energy (DOE) and has become one of the most popular and effective in the field [16]. In this simulation, the OpenStudio interface for the EnergyPlus engine was used to facilitate data input and geometry creation. The geometry design of the residential building was carried out in SketchUp and exported to the OpenStudio file. This means that the geometry, thermal zone, and space type were drawn and created using SketchUp, and the structures, materials, occupancy, internal loads, and schedule were modified using OpenStudio. The approach to energy efficiency simulation involved multiple steps, from modelling the physical building and setting the parameters in both SketchUp and OpenStudio. We used SketchUp to construct building geometry, determine space type, and boundary condition. For OpenStudio, the input parameters can be configured in tabs such as Site tab, HVAC system tab, and Simulation setting tab.

An energy evaluation was conducted on a residential building to refine the EnergyPlus computer model and align it with real-world conditions. The evaluation process involved gathering one year's worth of consumption data from utility bills and examining various factors that contribute to energy consumption, including indoor activities such as lighting usage, electric kettle usage, and the operation of a rice cooker. These parameters were not explicitly stated in the original report, highlighting potential errors in data analysis and simulation studies, particularly in relation to the air conditioning operation schedule, which significantly impacts energy consumption.

According to a study by [17], building energy simulations rely on accurate meteorological data, which plays a crucial role in measuring energy efficiency. Parameters such as ventilation, wind speed, temperature, and solar radiation gain are influenced by the building's location and its surrounding environment. Moreover, these parameters' energy-saving potential is highly dependent on climate factors, which may fluctuate over time due to climate change, as highlighted by [18].

To ensure the simulation model accurately reflects the real energy demand of the residential building, adjustments were made to the occupancy and activity parameters. By calibrating these factors, the simulation model can more accurately capture the energy consumption patterns of the building.

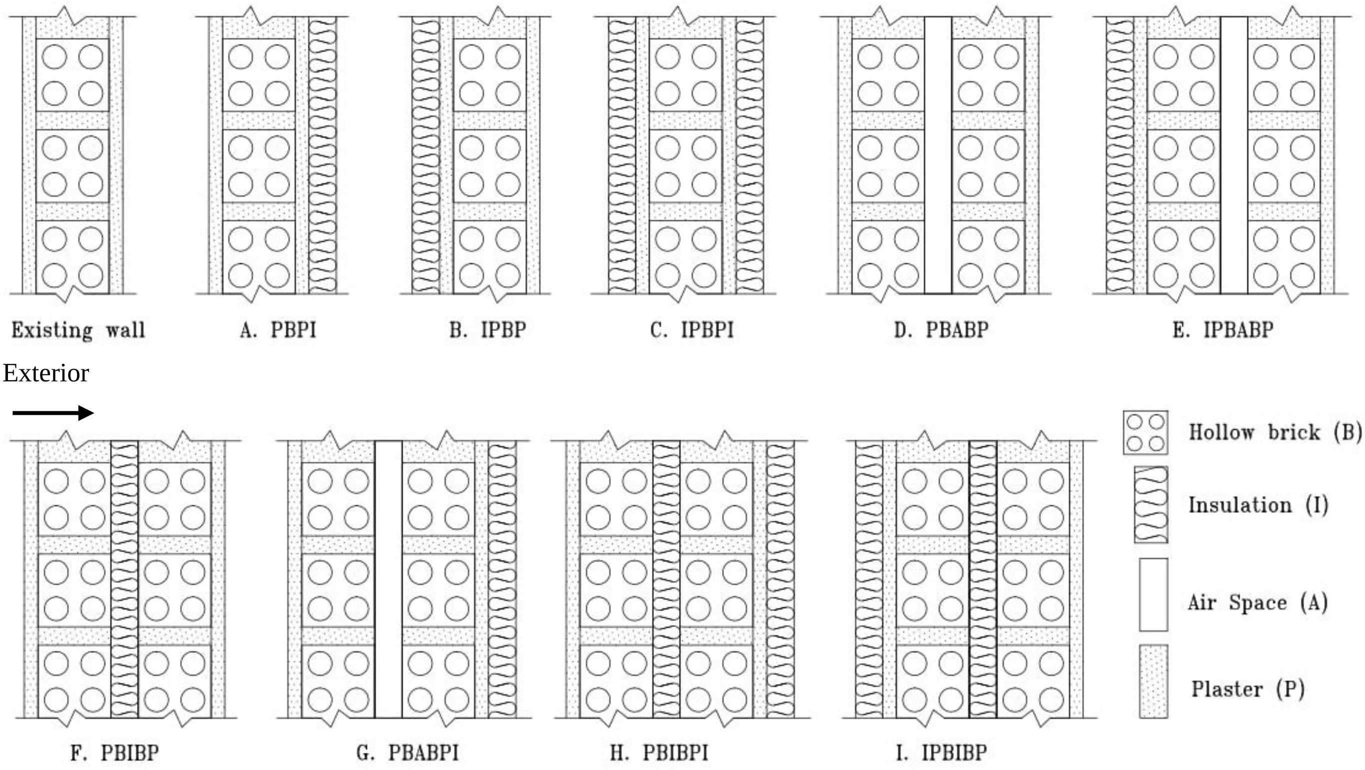


Fig. 2. Double brick walls and additional insulation types with simulation model

The calibrated model of the building under study incorporates two specific changes for analyzing the isolated energetic effectiveness: additional insulation on the existing walls and the replacement of a single-brick wall with a new model of double-brick walls, as depicted in Figure 2. These modifications were chosen to compare different insulation strategies and the impact of double-brick walls on energy efficiency.

In this study, the actual energy consumption of the residential building model was obtained from Electric du Cambodge (EDC). The building's annual energy bill for the year 2021 amounted to 6477.31 kWh, with monthly records of energy consumption available. These actual consumption figures serve as the baseline for comparison in this research.

3. RESULT AND DISCUSSION

The focus of the following analysis is to evaluate the energy savings achieved through the implementation of the proposed insulation wall and double-brick walls in the residential building. These models are commonly employed in EnergyPlus simulations to estimate the annual energy consumption of residential structures.

EnergyPlus generates detailed simulation output files along with summary reports, which are crucial for analysing and comparing the results. The primary objective of this modelling exercise is to conduct a comparative analysis of different simulation scenarios, specifically examining heat/cold load, heat gain/loss, and energy savings.

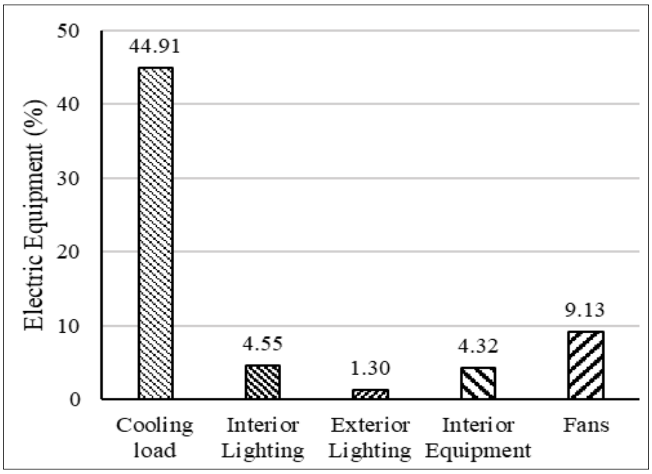


Fig. 3. Annual energy consumption simulation

Figure 3 illustrates that the highest energy consumption in the residential building stems from space cooling load, accounting for 44.91% of the total. Other contributors include interior lighting at 4.55%, exterior lighting at 1.3%, interior equipment at 4.32%, and fans at 9.13%. These findings further emphasize that a significant portion of residential electricity consumption can be attributed to air conditioning systems.

Consequently, a building that lacks proper insulation and is exposed to external elements through inefficient walls and windows will experience increased energy usage in order to maintain thermal comfort.

Table 5. The monthly actual energy and simulations value

Month	Actual Energy Consumption (kWh)	Simulation Consumption (kWh)	Error (%)
Jan	467.23	478.03	2.31
Feb	474.57	496.53	4.63
Mar	608.92	640.32	5.16
Apr	629.92	656.34	4.19
May	653.81	662.59	1.34
Jun	580.8	584.47	0.63
Jul	589.91	587.63	-0.39
Aug	561.05	563.42	0.42
Sep	493.7	492.19	-0.31
Oct	522.91	524.79	0.36
Nov	443.91	450.48	1.48
Dec	450.58	457.99	1.64

To validate the simulation results, a comparison is made with the actual monthly energy consumption data and the corresponding simulated values, as presented in Table 5. While the simulation inputs are accurately provided to the software, some unspecified parameters may lead to discrepancies between the simulated and actual values in certain months. However, the overall trend of the simulated energy consumption aligns with the actual values for the entire year. By utilizing EnergyPlus tools to modify and update the input data, the variation between monthly figures can be minimized. The difference between the actual and simulated rates of energy intensity for the year is found to be 60.13 kWh/m^2 and 61.22 kWh/m^2, respectively, indicating a difference of less than 1.78%.

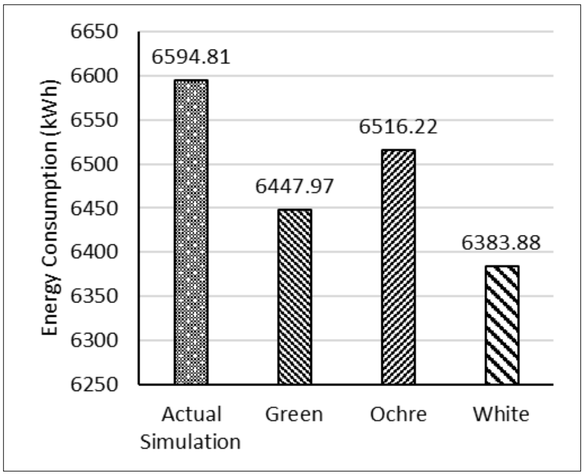


Fig. 4. Actual Energy Used and exterior insulation layer

The findings of the study indicate that the choice of colour paint for a building's exterior surface can have a significant impact on energy savings. According to a study by [19], varying the colour of the coating applied to the building's surface, from deep to light shades, leads to greater air conditioning energy savings. This effect is attributed to higher daily cooling demands and the resulting increase in energy savings.

Figure 4 illustrates the difference achieved by using different colour paints on the external wall layer compared to the actual simulation model. The results show that the application of green colour paint can reduce annual energy consumption by 2.23%, ochre colour by 1.19%, and white colour by 3.20%. This highlights the potential for energy savings through the selection of appropriate colour paints.

Additionally, research conducted by [20] found that the utilization of white colour paint on external surfaces can significantly reduce external surface temperatures by 14.8°C compared to other colours. This temperature reduction further contributes to energy savings.

Figure 5 presents the annual energy consumption results of various wall model simulations, indicating a range of energy reduction from 980.29 kWh to 1599.89 kWh. The simulation outcomes demonstrate the impact of additional insulation on different sides of the wall for each model.

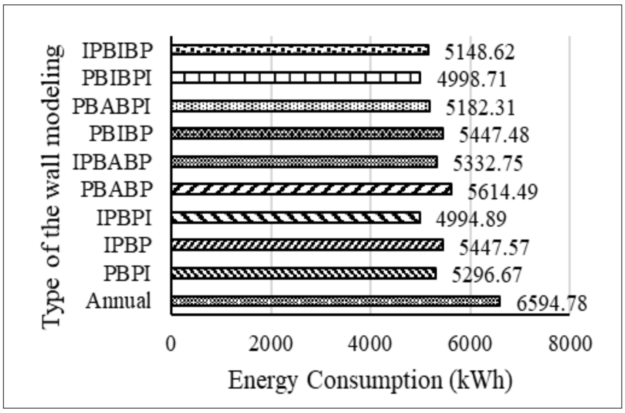


Fig. 5. Comparison of Actual energy use vs modified wall

For Type PBPI, where interior layer insulation was added, the simulation shows an annual energy consumption reduction of 5296.67 kWh. This corresponds to a 19.68% decrease in energy consumption for the studied flat model, resulting in a total annual energy consumption of 5447.57 kWh. Type IPBP, which had additional insulation on the exterior layer of the wall, achieved an annual energy consumption reduction of 1147.21 kWh, equivalent to a 17.40% decrease. The total annual energy consumption for Type IPBP amounted to 5332.75 kWh.

Type IPBPI, with insulation added to both the exterior and interior sides of the wall, achieved a 24.26% reduction in energy consumption, resulting in 1559.89 kWh of the total energy consumption of 4994.89 kWh.

Type PBABP, representing the double-brick wall without insulation, achieved an annual energy consumption reduction of 980 kWh, which accounts for a 14.86% decrease in energy consumed.

Additional insulation was incorporated into the double-brick walls for Types E to I. For Type IPBABP, PBIBP, and PBABPI, the simulations showed reductions in annual energy consumption by 1262.03 kWh (19.14% decrease), 1147.3 kWh (17.40% decrease), and 1412.47 kWh (21.42% decrease), respectively. The total energy consumption for these types was recorded as 5447.48 kWh, 5182.31 kWh, and 4998.71 kWh, respectively.

Type PBIBPI and Type IPBIBP, which feature additional insulation on the double-brick walls, demonstrated further improvements in energy conservation. These types achieved reductions of approximately 24.20% (1596.07 kWh) and 21.93% (1446.16 kWh) in total energy consumption, compared to the preceding types, which had total energy consumption values of 4998.71 kWh and 5148.62 kWh, respectively. The findings of the simulation demonstrate the potential for significant energy savings, ranging from 14.86% to 24.26%, depending on the insulation configuration and wall type.

Table 6. Utility costs versus savings for each simulation type

Type of the simulation	Average monthly cost (USD)	Annual utility cost (USD)	Annual saving (USD)
Actual Simulation	97.82	1173.87	-
PBPI	78.57	942.81	231.06
IPBP	80.81	969.67	204.20
IPBPI	74.09	889.09	284.78
PBABP	83.28	999.38	174.49
IPBABP	79.10	949.23	224.64
PBIBP	80.80	969.65	204.22
PBABPI	76.87	922.45	251.42
PBIBPI	74.15	889.77	284.10
IPBIBP	76.37	916.45	257.42

The energy models and simulations effectively demonstrated the efficiency of each wall type in reducing the building's energy consumption. To further evaluate the viability of these options, a cost-benefit analysis and payback period assessment will be conducted to determine the most favourable retrofit option for the building.

Table 5 provides valuable insights into the potential energy savings achieved by each simulation type, along with the associated annual cost savings. The results indicate that implementing the different wall types can lead to annual energy savings ranging from $153.58 to $263.87, depending on the specific wall configuration.

The utility costs considered for both the understudy simulation and each simulation type are based on Electricite du Cambodge (EDC) electricity power rates for kilowatt-hours (kWh). As of January 1st, 2020, EDC charges $0.178 per kWh up to 201 kWh. The kWh rates used in the cost calculations align with the EDC rates, and the energy bill rates will determine the cost data in annual dollars per kWh. These costs will be divided into base cases and the average monthly payments associated with each simulation.

Analysis of investment costs

Based on the analysis of the payback period using the provided data, it is evident that these retrofit options offer significant benefits for homeowners who plan to reside in their homes for a minimum of 40 years. Although 40 years is a considerable period in the lifespan of a home, it is important to note that the return on investment will be realized gradually over time. Therefore, it is essential to exercise patience when considering these retrofits.

Table 7 details the expenses associated with retrofitting residential constructions, specifically focusing on existing walls. The table clearly shows that adding insulation to single-brick walls is a more cost-effective solution compared to double-brick walls. The total wall area requiring upgrades is measured at 102 square meters.

Table 7. Cost estimate for retrofitting a wall

Type of wall simulation	Wall retrofit costs		Total retrofit (USD)
	Materials (USD/m^2)	*Labor (USD/m^2)*	
PBPI & IPBP	6.67	1.23	806.24
IPBPI	13.34	1.23	1486.96
PBABP	9	3	1224.67
PBIBP	12.17	4.23	1673.72
IPBABP & PBABPI	15.6	4.23	2023.77
PBIBPI & IPBIBP	18.84	4.23	2354.43

For retrofit categories PBPI and IPBP, the investment amounts to $6.67 per square meter. This means that approximately $13.34 per square meter is required to implement two layers of insulation on the existing wall. On the other hand, Type PBABP, which involves adding a layer to the brick wall, incurs a cost of $9 per square meter.

Among the various types, E to I is the most expensive in terms of retrofitting costs. Type PBIBP necessitates an expenditure of $12.17 per square meter, while Types E and G require $15.6 per square meter. Lastly, Types PBIBPI and IPBIBP have the highest retrofitting cost at $18.84 per square meter.

Figure 6 provides valuable insights into the long-term benefits of insulation retrofitting on existing walls. The data demonstrates that, after approximately three years, the homeowner began to experience a net benefit of $133.48 from the addition of interior insulation to the walls. With a payback period of eight years, Type IPBPI (insulation on both sides of the wall) appears to be the most favourable option among the nine types considered.

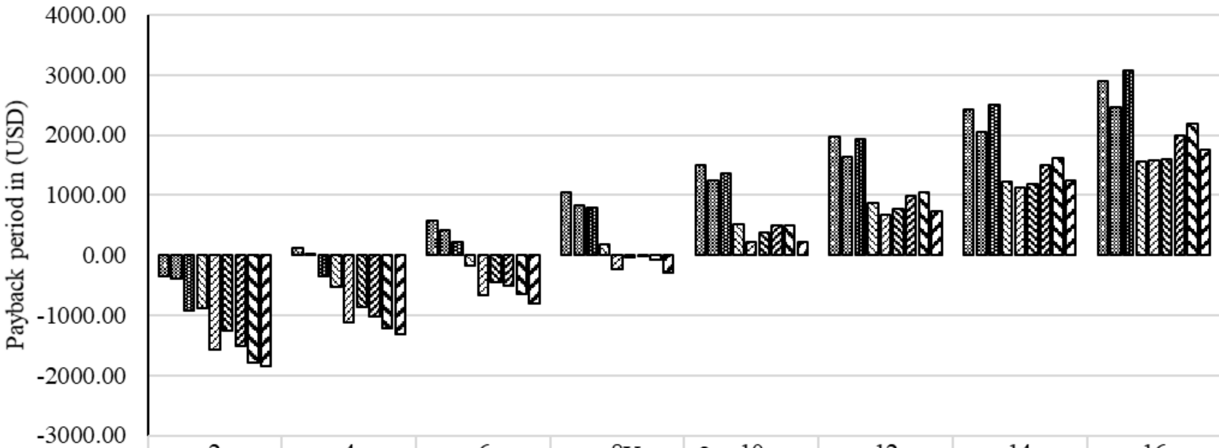
However, it is important to note that the residential building in this case study has a unique flat building style that restricts the use of exterior insulation. In such a scenario, Type PBPI becomes the preferred choice. The initial retrofitting of the existing wall played a significant role in showcasing the energy performance improvements achievable with modern standard walls in this residential building.

Previous studies, such as [21], have demonstrated that the addition of insulation materials to different building elements, including walls and roofs, can lead to energy consumption reductions ranging from 13% to 50%. Additionally, it was highlighted that installing insulation materials can effectively lower overall building energy consumption [22].

While a double-brick wall is more efficient than a wall without insulation, the energy savings and payback period are relatively modest. Moreover, a wall without insulation proves to be ineffective in preventing solar heat gain from west-facing facades during the summer. Therefore, investing slightly more in additional insulation yields considerably more significant improvements in a building's energy efficiency.

Among the nine options considered, retrofitting the wall with insulation on both the interior and exterior sides emerge as the best choice. Residential buildings greatly benefit from the added insulation, which offers a wide range of options to suit different specifications. The insulation and thermal breaks help reduce heat absorption through the wall, while Low-E coatings contribute to minimizing direct solar radiation gain indoors.

The retrofit options of Type PBPI and IPBPI, which involve adding insulation to the existing single-brick wall, strike a balance between cost and efficiency, with a payback period of around three years. The payback period extends to five years for Type PBABP and PBABPI. For Type IPBABP, PBIBP, PBIBPI, and IPBIBP, the wall retrofitting pays back after six years. It is worth noting that the cost of materials and labour associated with retrofitting is higher for double-brick walls compared to single-brick walls, which contributes to the shorter payback period of the walls.



	2	4	6	8	10	12	14	16
PBPI	-344.11	118.01	580.14	1042.27	1504.40	1966.52	2428.65	2890.78
IPBP	-397.83	10.57	418.98	827.39	1235.79	1644.20	2052.61	2461.01
IPBPI	-917.40	-347.84	221.72	791.28	1360.84	1930.41	2499.97	3069.53
PBABP	-875.69	-526.70	-177.72	171.26	520.25	869.23	1218.21	1567.20
IPBABP	-1574.49	-1125.20	-675.92	-226.64	222.64	671.93	1121.21	1570.49
PBIBP	-1265.28	-856.84	-448.40	-39.96	368.47	776.91	1185.35	1593.79
PBABPI	-1520.93	-1018.09	-515.25	-12.41	490.43	993.27	1496.11	1998.94
PBIBPI	-1786.23	-1218.03	-649.83	-81.63	486.57	1054.78	1622.98	2191.18
IPBIBP	-1839.60	-1324.76	-809.93	-295.10	219.73	734.57	1249.40	1764.23

The estimated payback period for each type of simulation is under 16 years

4. CONCLUSION

This study employed simulation software to compare the total energy consumption of nine different wall types, including double-brick walls, for both design testing and retrofitting of existing walls with additional insulation on the inside, outside, and both sides. The research focused on a residential building in Phnom Penh, specifically a townhouse-style structure, with a total floor area of 41.8 square meters and a Window to Wall Ratio of 0.18%.

The results highlight that a significant portion of electricity consumption is attributed to cooling loads from air conditioning, with the energy being produced regionally. The primary objective of this research is to provide recommendations for selecting the most suitable wall type based on the specific conditions of the case study.

The building and material constructions utilized in the residential building model represent the commonly used practices in Cambodia. The findings demonstrate the following:

The choice of white colour paint for the exterior walls has a considerable impact on energy savings compared to other colours, resulting in a potential reduction of annual energy consumption by 3.20%. Therefore, the influence of colour paint on energy consumption should be taken into account.

The addition of insulation to an existing single-brick wall leads to a significant decrease in annual energy consumption by 19.68%. Among the nine types considered, interior insulation proves to be the most effective option and is recommended for implementation in this case study. Residential buildings greatly benefit from the addition of insulation with interior layers, which offer various choices to suit different specifications.

For individuals interested in improving the efficiency of their homes, the results of this study serve as a useful reference, showcasing the impact of changing wall properties on energy consumption.

It is important to acknowledge that while EnergyPlus is a user-friendly energy simulation program, it has certain limitations that may introduce errors in the study's results. Additionally, factors such as building orientation, overhangs, shading, infiltration, and the physical characteristics of the residential building can significantly impact energy savings. Moreover, the wide variety of wall alternatives, frames, glazing windows, and occupancy behaviours can lead to variations in results among different individual cases.

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